

RDRAM: Past, Present, Future

Name: Billy Garrett

Title: Manager of Strategic Marketing

Company: Rambus Inc.



San Jose January 23-24, 2001



Taipei February 14-15, 2001

Agenda

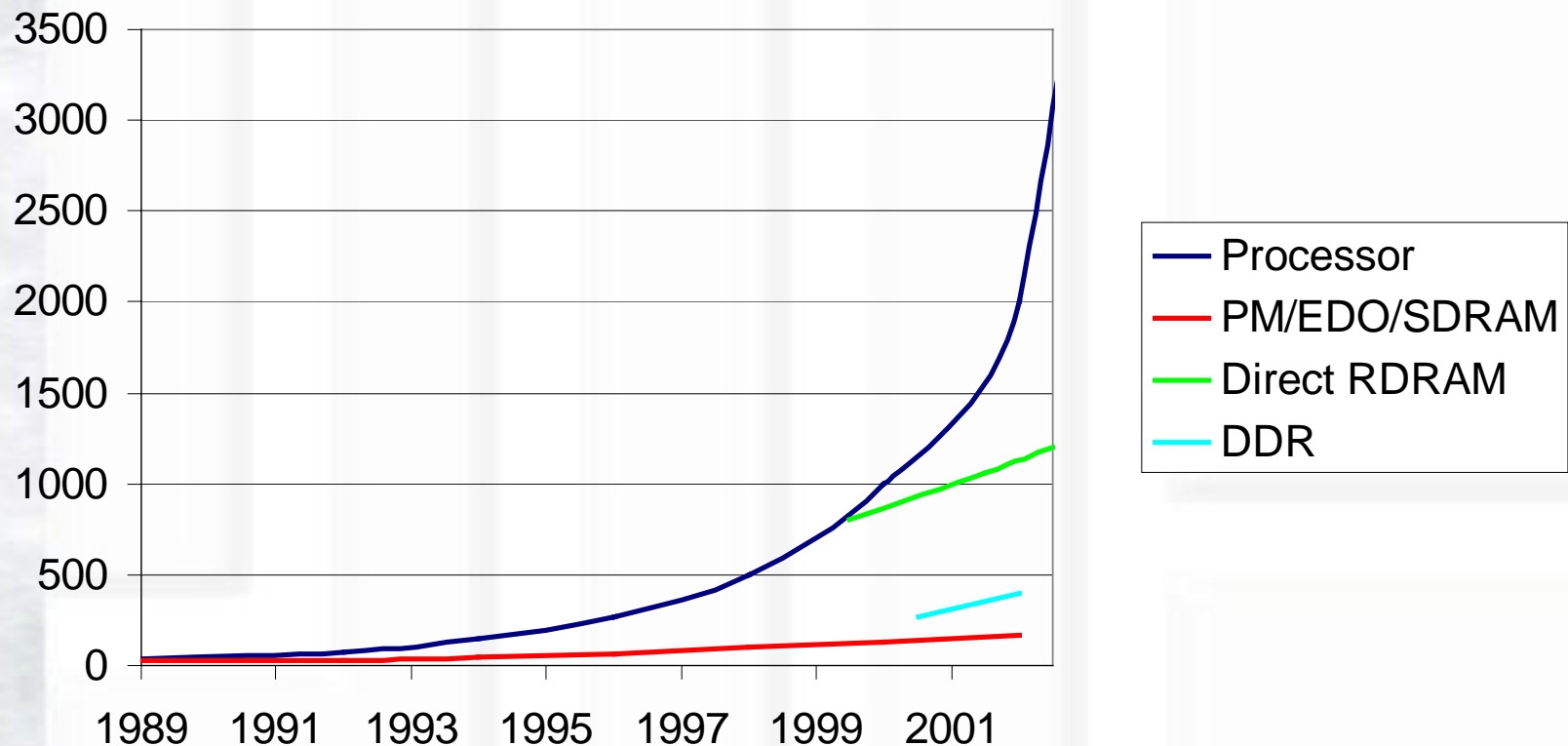
- The need for bandwidth
 - Processor bandwidth increases
 - Longevity, scalable solution
- Rambus' role as industry enabler
 - Background of development
 - Infrastructure, validation and devices
- RDRAMs in performance systems
- The future of Rambus technology
 - Signaling, RDRAM roadmap

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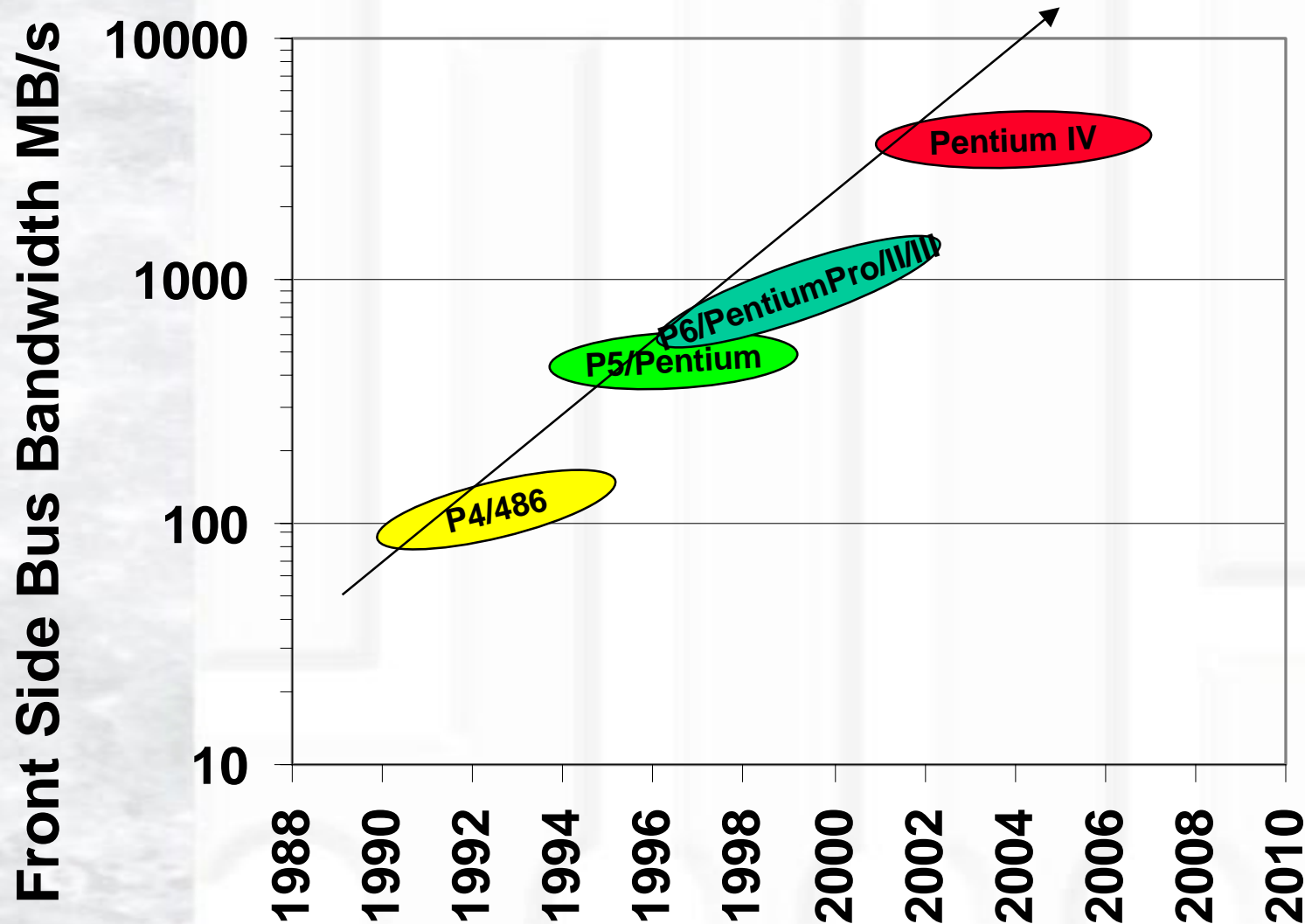
Solving the Growing Bandwidth Gap

Processor Frequency vs DRAM Data Rate



- Rambus technology reduces the gap
- Intel predicts 10 GHz processors in 2005

Growing Front Side Bus Bandwidths



- Memory subsystem needs to keep up with the bandwidth of the FSB
- Growing graphics demands may demand more memory BW, especially for UMA architectures



Brief Rambus History

- Founded in 1990 to solve the memory bandwidth bottleneck
- First application: SGI workstation 1995
- First high-volume application: Nintendo 64
 - Introduced: Summer 1996
 - First consumer 500 MHz memory subsystem
 - Still in production today



Why Intel Chose RDRAM in 1996

- Identified a need for a next generation DRAM
 - Match anticipated leap in processor performance
- Proven signaling
 - Mass production of Nintendo 64
- Proven development model
 - Compatibility across vendors
 - Quicker time to market
- System expertise
 - Goal to get to 800 MHz, two bytes (1.6GB/s)
 - Scalable
 - Solution needs a long life - 5 year goal



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Rambus Enabled Quick Time to Market

- First RDRAM silicon working in 15 months
- First system shown less than 6 months later
 - Fall Comdex 98 first showing by Intel
- First production system shipped in 1999
- 100's of partners
 - Infrastructure: connector companies, clock companies, module companies, PCB suppliers, tester companies, silicon suppliers, etc.
 - Multiple RDRAM partners

Rambus Enabled Common RDRAM Design Implementation

- Complete system reference design
 - Proven design promotes compatibility and interoperability
 - Detailed implementation package
 - Reference schematics
 - Layout
 - >500 pages of documentation
 - Simulation decks
 - Reflects >60 man-years of development
 - Automated characterization suite for identifying yield improvement
 - Current RDRAM Yield >90% at top manufacturers

Rambus Enabled High-Speed ATE

- Before Rambus:
 - No capability to test >200 MHz in 1997
 - No consistent test methodology
- Rambus worked with the ATE industry
 - Develop test capability up to 1.3 GHz
 - Created a tester spec for testing RDRAM that includes:
 - Description of data sheet parameter under test
 - Relevant test conditions such as pin timing, input voltage and power supply settings affecting the DUT
- RDRAM manufacturing readiness
 - Single site correlation studies to achieve ATE accuracy
 - Multi-site correlation studies to enable cost effective, multi-site systems
- RIMM module test readiness
 - ATE module, low-cost at speed testers, PC based tester enabled



64 site Ando Tester

Rambus Developed ATE Tools

- Rambus-created test methodology
 - Standard loadboard design
 - Test socket evaluation
 - Tester calibration procedures and on-site training
 - Comprehensive test vectors
- Test cost reduction
 - Joint work with RDRAM partners
 - Developed Best Known Methods to reduce overall test time
 - Process improvement reduces test program development time
 - Standard methodology reduces time-to-market and test R&D cost



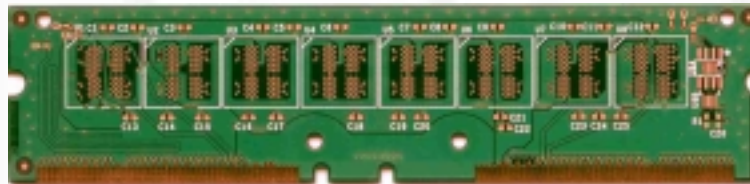
Rambus Enabled Clock Chip Design

- Complete reference schematic
 - Promotes interoperability and system performance
- Design validation
 - Rambus worked with test equipment vendors to develop validation methodology and specialized test fixtures
 - Verification flow tests system level parameters: jitter, phase drift, slew-rate, output impedance & voltage levels, power supply tolerance
 - Independent test labs using standardized equipment ensures compatibility
- Multiple vendors validated



Rambus Enabled Low Cost Module Design

- Standard reference designs:
 - Designed for 800 MHz reliable operation using standard low-cost FR-4 technologies
 - Used by all module manufacturers
 - Achieve familiar form factor to PC OEMs
 - 6 Layer cost-reduced PCB gerbers use PC100 design rules



- Supplier enabling and quality control
 - 17 world-wide low-cost producers enabled in US, Japan, Korea, Taiwan; Yields >95%

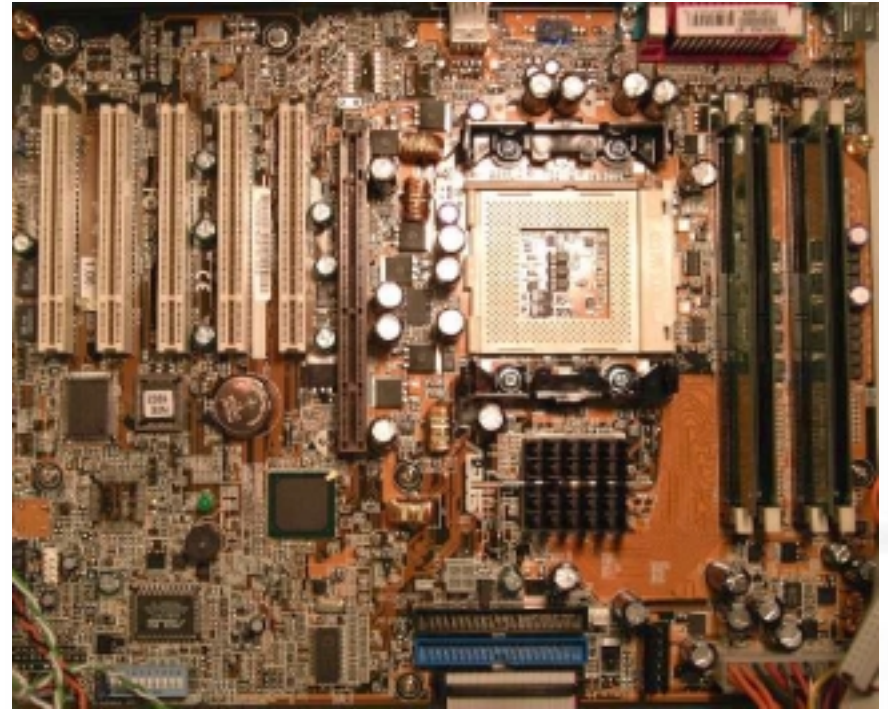
Rambus Enabled RIMM Connector

- High-frequency operation with:
 - DIMM-like form factor
 - Same cost structure ~\$0.50
 - High reliability and insertion
- Comprehensive connector validation
 - Electrical parameter verification
 - Mechanical reliability, shock & vibration testing



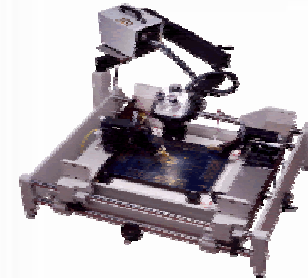
Rambus Enabled Motherboards

- Reference motherboard RDRAM Channel layout
 - Guidelines for integrating connector with motherboard for seamless transmission line
 - Developed comprehensive Rambus Channel layout guide
 - Motherboard/connector/module combination thoroughly analyzed electrically and mechanically



RDRAM/RIMM Module Validation

- Multi-tier testing strategy
 - RDRAM component
 - RIMM module
 - System level
- 4 independent test laboratories enabled world-wide



Photos courtesy of Agilent and Gigatest Labs.



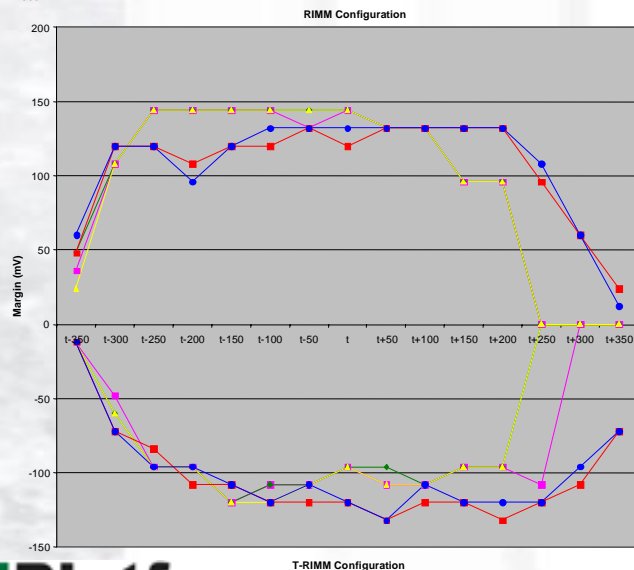
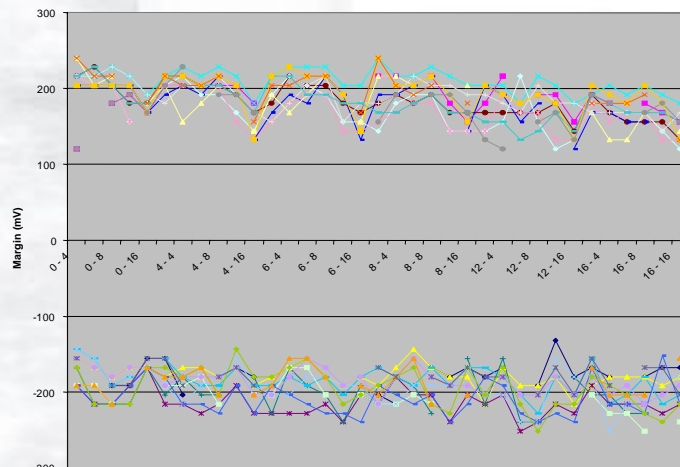
- Standardized equipment and procedures
 - Rambus-developed software and analysis tools
 - Precision AC timing and functional testing on ATE equipment - all test labs correlated with Rambus
 - Extraction of signal integrity RLC components
 - Well-calibrated probe station, measurement fixtures, network analyzer for +/-2ps resolution
- Verifies specification compliance and identifies improvement for RDRAM components, RIMM module assembly

System and Platform Validation

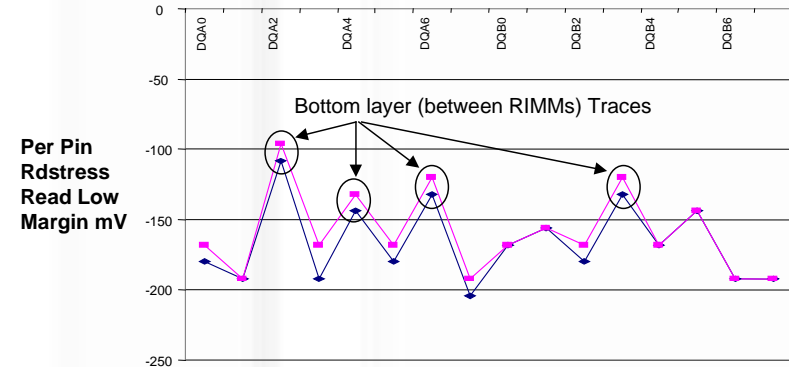
- Robustness for multiple systems is a LOT of work
 - 35 RIMM combinations
 - ~20 densities/core types/speeds
 - > 10 RDRAM/RIMM vendors
 - 5 different controllers and multiple motherboard vendors
 - Close to 100,000 combinations to make sure true interoperability across many components from many vendors
- Tools/Tests
 - Developed methodologies for effective debug at 800 MHz
 - Developed targeted tests and tools needed for automated (voltage/timing) margining
 - Design guide lines and reviews for major OEMs



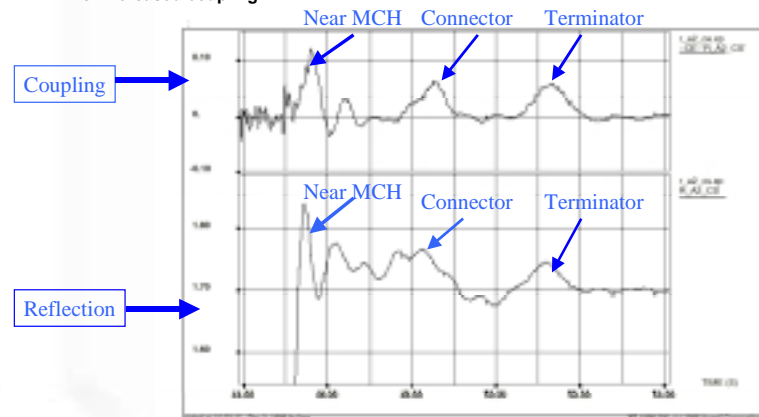
Examples: System Data



T-RIMM Configuration

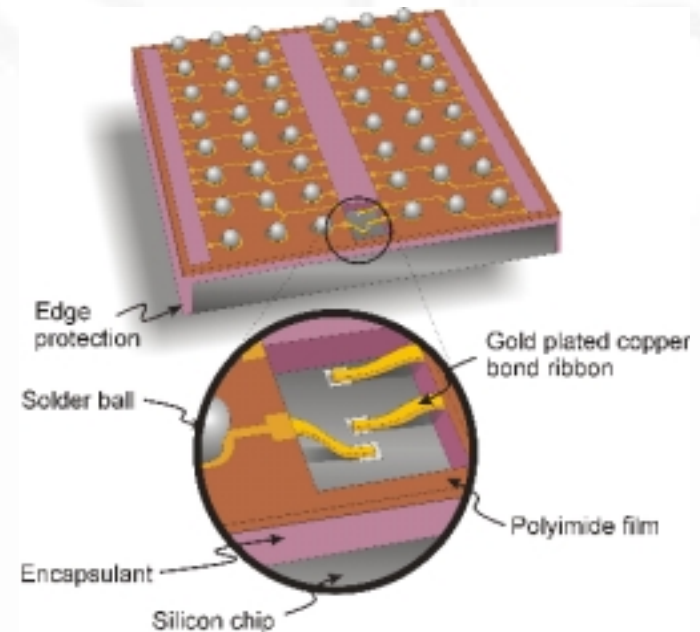


- Step response (single line switching from low to high) analysis used to identify areas of higher reflections
- Coupling analysis (victim line kept quiet while all other lines switch) used to identify areas of increased coupling



Package

- First to use CSP for DRAMs
 - uBGA, mBGA
- Three package ball-out (edge, 9X8, 16X6)
- Thermal validation studies
- Mechanical reliability studies
 - Set standards for RIMM module reliability
 - Completed multiple reliability programs
- Package cost reduction program



Direct RDRAM Status

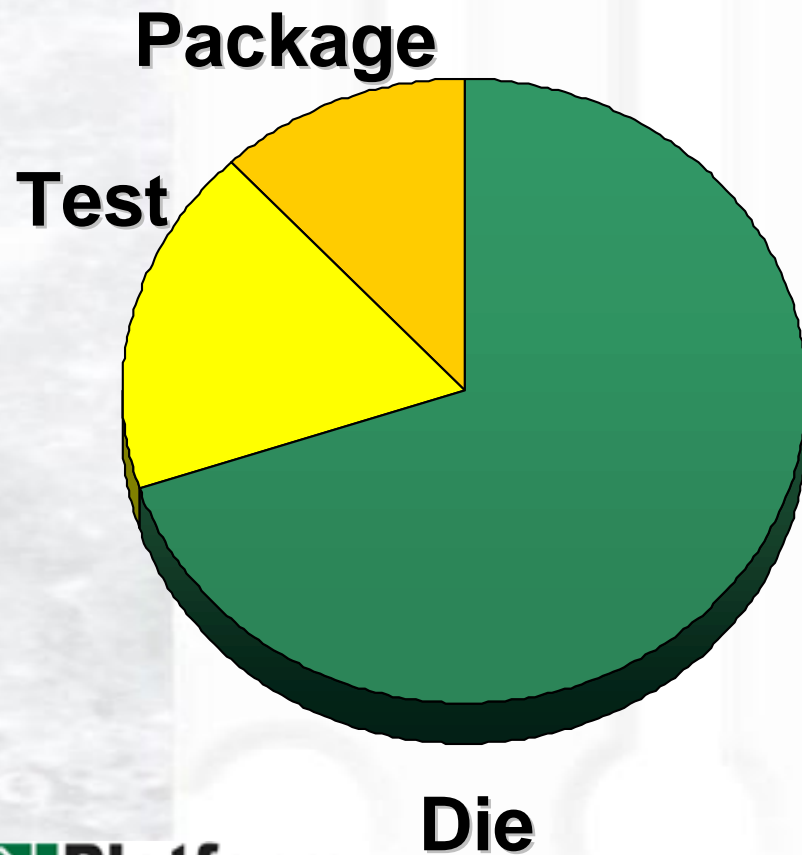
Vendor	128/144Mb Validation	256/288Mb Validation
Samsung	✓	✓
NEC	✓	✓
Toshiba	✓	✓
Infineon	✓	Q101*
Hyundai	✓	Q101
Micron	✓	Q201

Individual Vendors should be contacted for up to date schedules

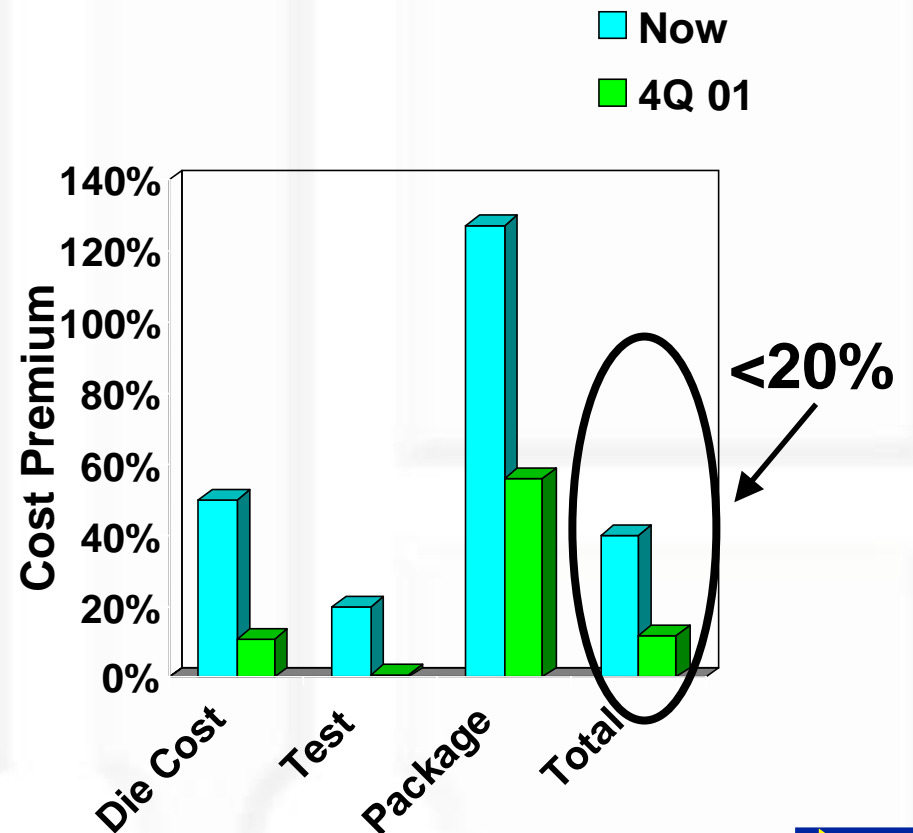
*Infineon 288 Mb RDRAM passes except package RLC

RDRAM Cost Decreasing

DRAM Cost Breakdown



RDRAM vs SDRAM



Big reduction in cost by year end

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RDRAM in Consumer Applications



Set Top Boxes

Panasonic

Mitsubishi

Hitachi

Pioneer

Sony

Undisclosed US OEM



PlayStation®



LCD Monitors

Eizo

Matsushita



HD/DTVs

Panasonic

Mitsubishi

Sanyo

Sony

Network Communication Trends

Communications
Partners

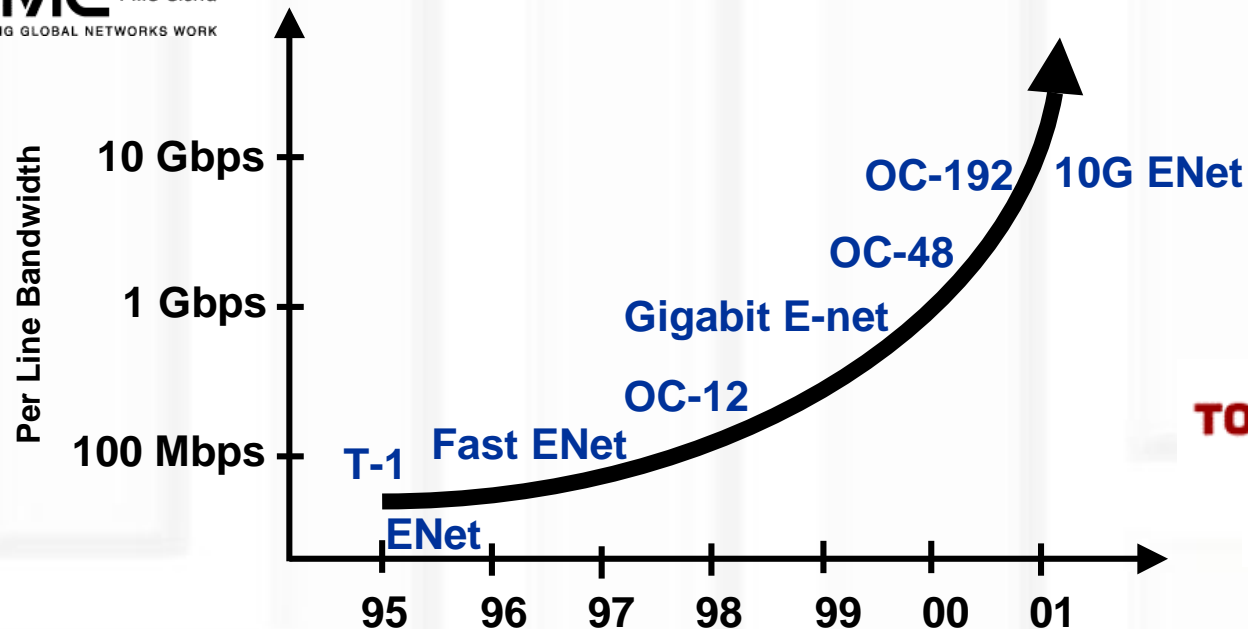
SWITCHCORE

PMC PMC-Sierra
MAKING GLOBAL NETWORKS WORK

VITESSE
SEMICONDUCTOR CORPORATION

ArrowPoint
COMMUNICATIONS

- Line bandwidths & network services increasing
- Intelligence moving to linecard



ASIC
Partners

TEXAS
INSTRUMENTS

TOSHIBA



LSI LOGIC

NEC

IBM



Agilent

Low-cost, high-performance solution needed:

- RDRAM memory
- Chip-to-chip interconnect



Server: Compaq Alpha EV7/EV8

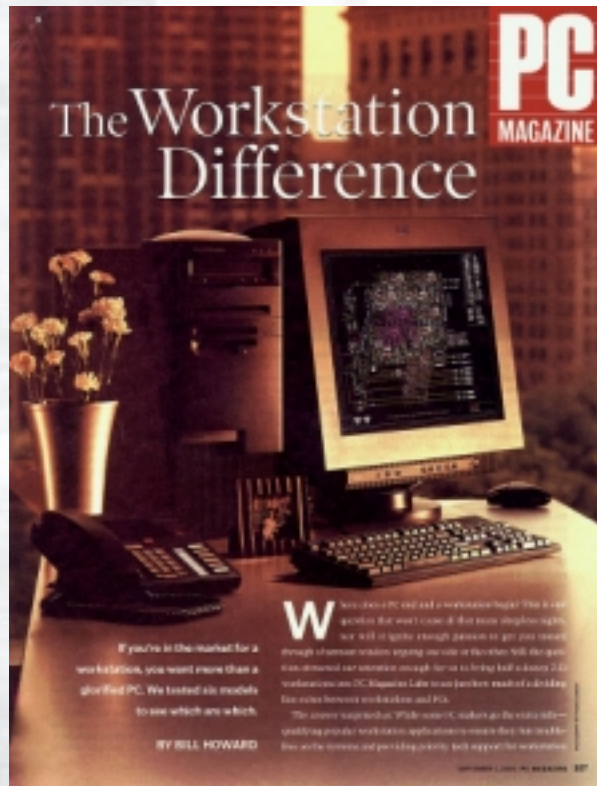
- Next-generation Alpha processors
 - Direct RDRAM interface integrated on CPU
 - 2002 production
- Current products span single-processor to 32-way Servers
- Integrated RDRAM memory controller
 - Low latency: 30 ns
 - High-bandwidth: 6GB/s read or write



“RDRAM is the only DRAM product that meets Alpha's requirements for high-bandwidth per pin, low latency and high storage capacity with a low-voltage interface facilitating direct incorporation onto the processor.”

- Peter Bannon, EV7 System Architect, Compaq

RDRAM: 75% of PC Workstations



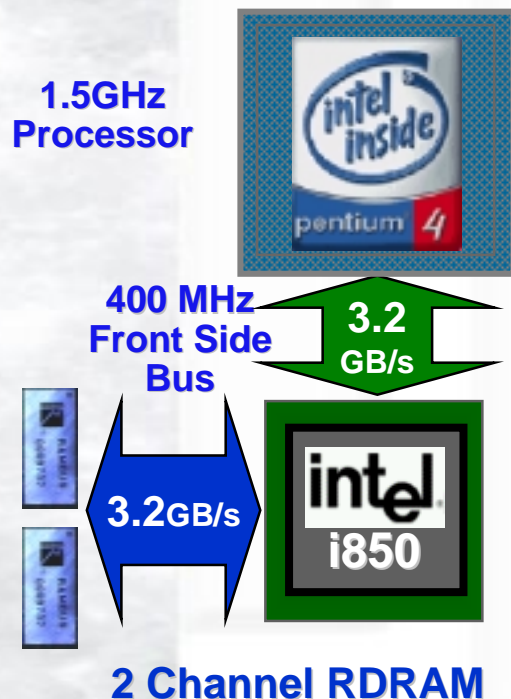
◆ IN THIS ROUNDUP: Six 2-D Workstations

Rating	Product
●●●○○	Compaq Professional Workstation AP550
●●●●● ✓	Dell Precision Workstation 420 MiniTower
●●●○○	Gateway E-5400 800
●●●●●	HP Kayak XM600 PC Workstation
●●●●●	IBM IntelliStation M Pro
●●●●●	Micron ClientPro Dx5000



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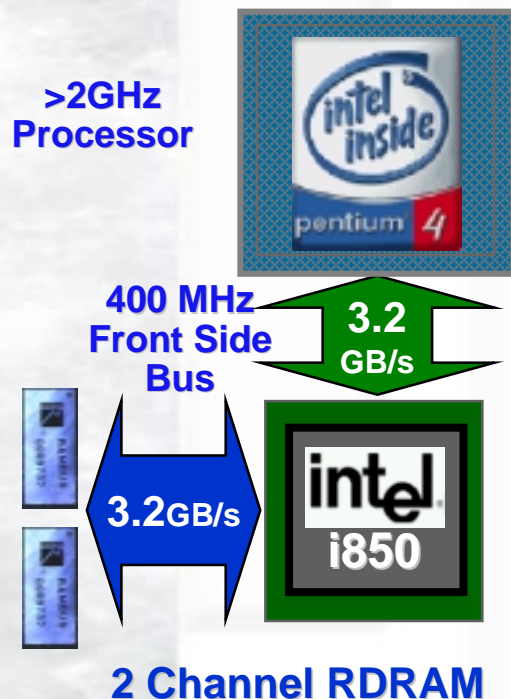
Standard view Extended view Printable Summary E-VALUE CODE: 6/845 - 8100RL

P4 Motherboards shipping from major Taiwanese manufacturers including: Asustek(P4T), Gigabyte(GA-8TX), MSI (850 Pro) and AOpen(AX4T)



Pentium 4 + RDRAM

Headroom for the Future

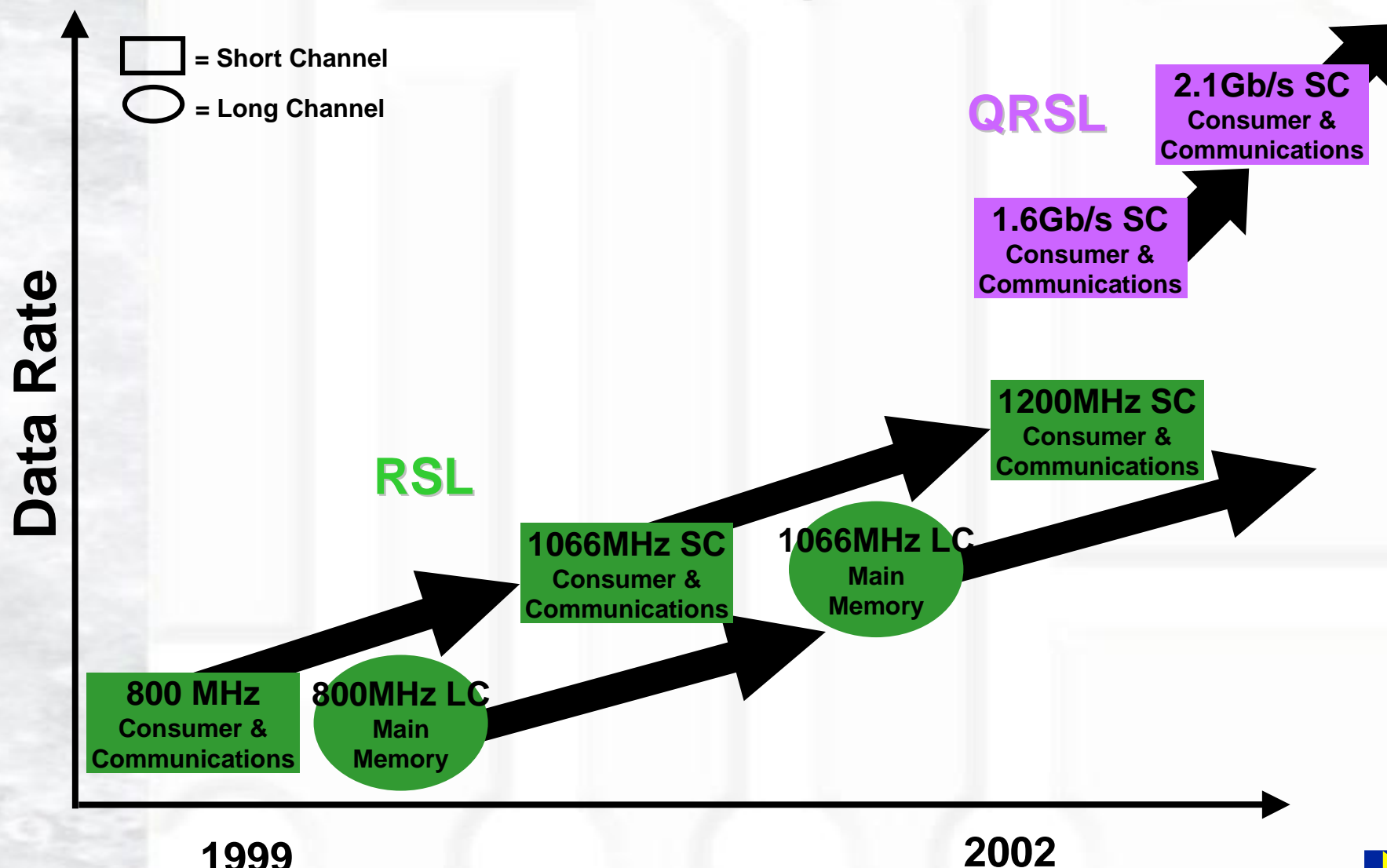


- CPUs are only going to get faster
 - RDRAM memory is scaleable
- Performance matters
- Do users want more performance?
 - OF COURSE THEY DO!
- Best of class workstations → • Best of class desktops

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RDRAM Technology Roadmap

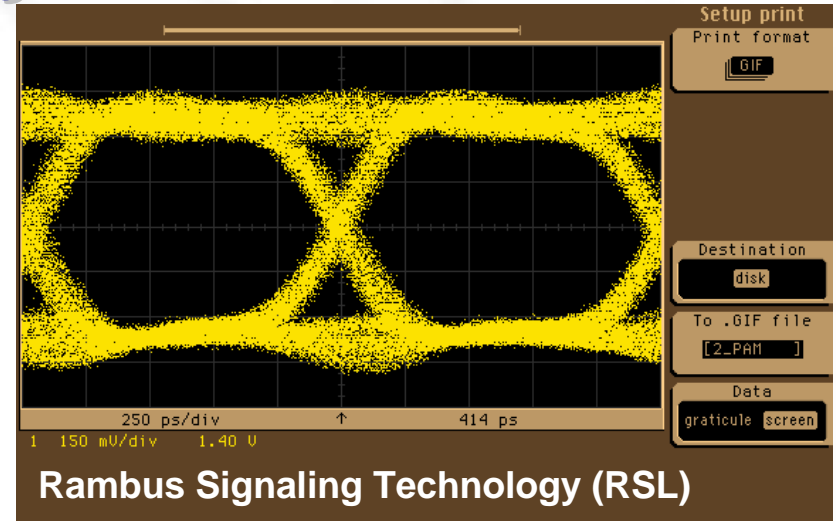


QRSL: Revolutionary Performance

- High-performance, next-generation I/F
 - Announced at VLSI Circuits Symposium: 16 June 2000
 - >2 Gb/s/pin signaling using Quad Rambus Signaling Level (QRSL)
 - 2x BW in same footprint as Direct
- Significant interest
 - *Consumer, Networking and Chip-to-Chip*
 - First licensee: Toshiba
- Engineering status
 - Test chip running @ full BW
 - 0.25um UMC process
 - RDRAM: CSP/COB package
 - Controller: Full-width RAC like interface in BGA package

Level 1

Level 2

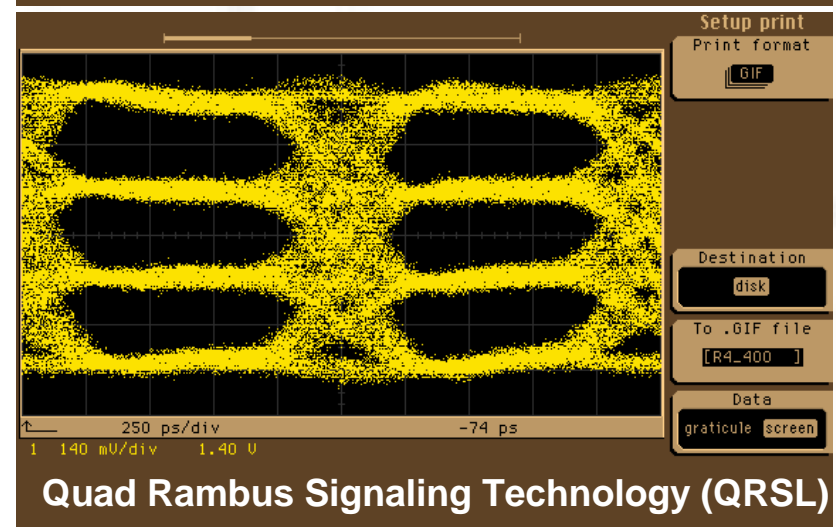


Level 1

Level 2

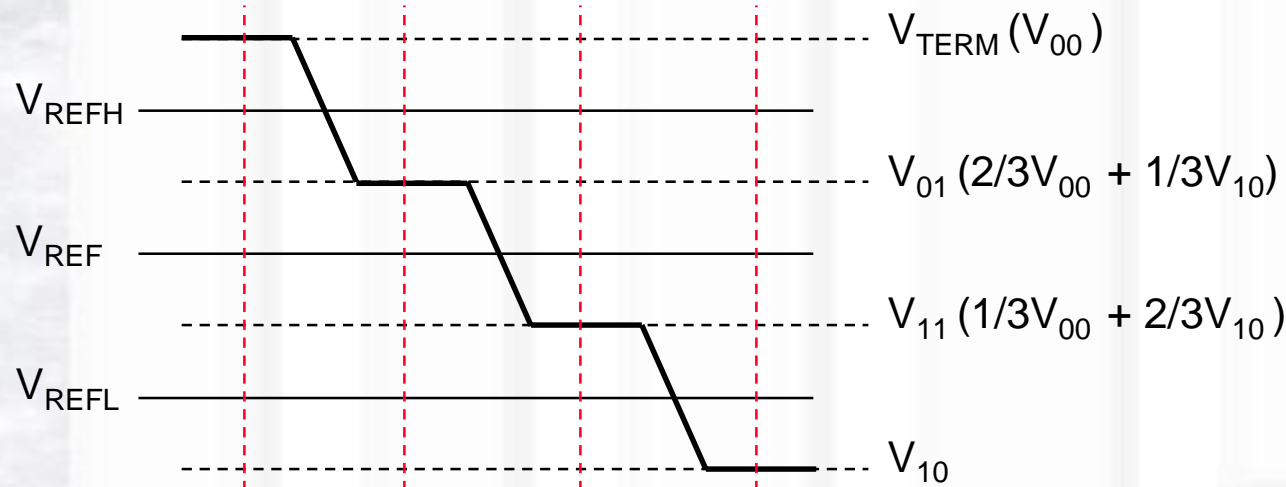
Level 3

Level 4



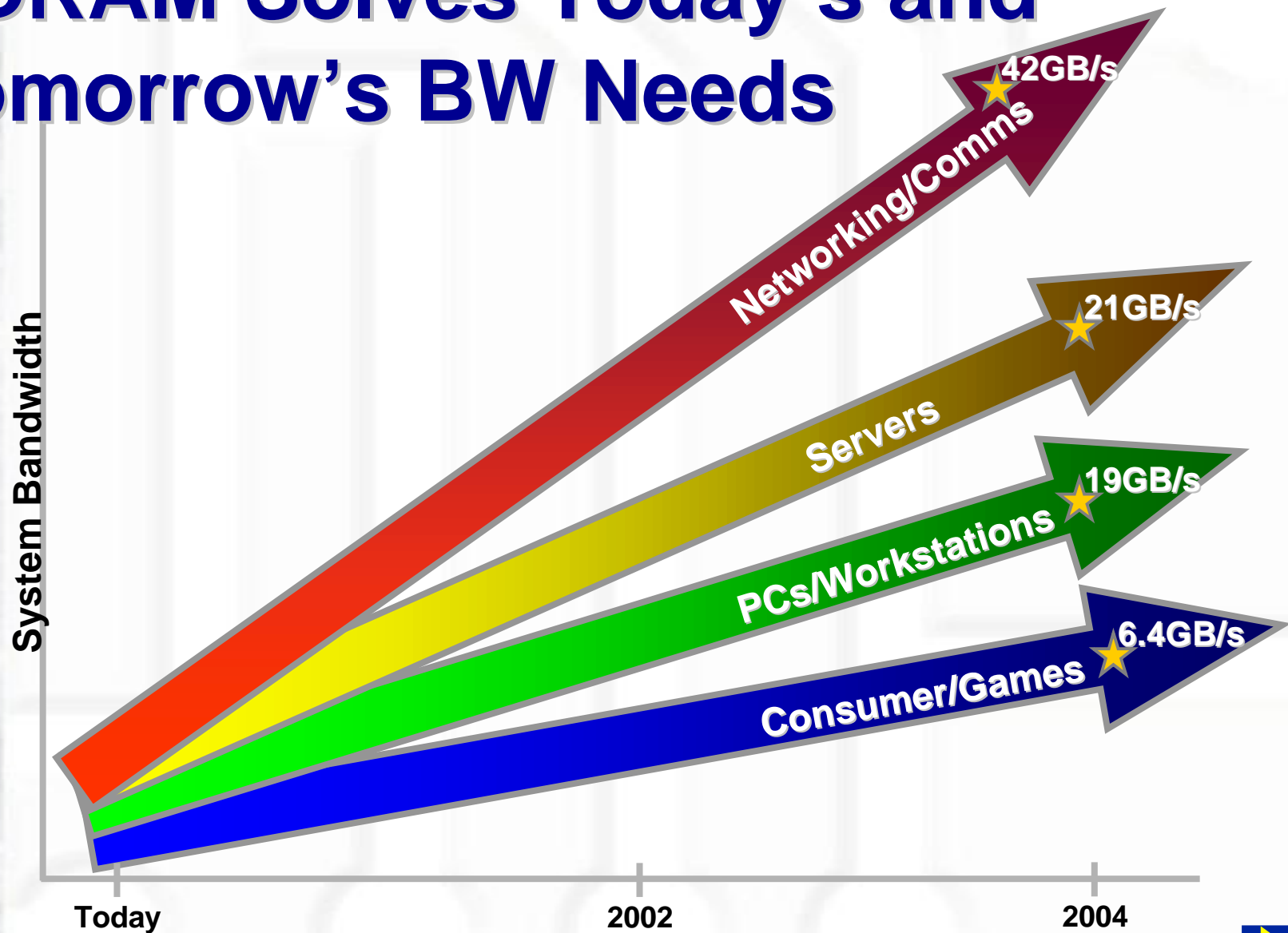
QRSL Signaling Levels (QRSL)

MSB	0	0	1	1
LSB	0	1	1	0



- 4 level signaling
- Backwards compatible with RSL using MSB
 - $V_{\text{TERM}} = 1.8\text{V}$, $V_{\text{REF}} = 1.4\text{V}$

RDRAM Solves Today's and Tomorrow's BW Needs



The Rambus Industry is Ready



Summary

- Applications need ever increasing performance
- RDRAM is best suited for best-of-class systems
- Rambus is continuing to work with the industry to enable high-volume, low-cost production
- Rambus and partners are engineering future higher performance solutions